EASTERN RED BAT (*LASIURUS BOREALIS*) RESPONSE TO FIRE STIMULUS

DURING TORPOR

A Masters Thesis

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Jason Thomas Layne

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ABSTRACT

Current forest management practices during winter utilize prescribed fires to increase plant diversity and reduce competition for desired tree species. Concerns have arisen for eastern red bats (*Lasiurus borealis*) that utilize fallen leaf litter for roosting during cold ($<10^o$C) temperatures. I studied responses of torpid leaf litter-roosting red bats (n = 18) to stimuli from fires in an experimental open area environment. Latencies of each behavior associated with awareness to the stimuli of fire (first response, arousal, and flight) were correlated to ambient weather parameters temperature, wind speed, and relative humidity at three different time periods. Latencies of all behaviors were significantly negatively correlated to temperatures, showing that higher temperatures corresponded to decreases in reaction times. Increased wind speeds just before the start and during a fire were correlated with latencies of first response and arousal behavior, and were also negatively correlated with latency of flight response throughout the time periods measured. Levels of carbon monoxide throughout a trial were smaller compared to laboratory smoke trials and data from an actual prescribed fire. I recommend conducting winter fires on days when temperatures are $\geq 10^o$C and starting the fire on a north-facing slope in order to give eastern red bats a chance to passively rewarm and react to an imposing fire.

KEYWORDS: eastern red bat, winter, prescribed fire, torpor, forest management

This abstract is approved as to form and content

Dr. Lynn W. Robbins
Chairperson, Advisory Committee
Missouri State University

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INTRODUCTION

Eastern Red Bat

The eastern red bat (*Lasiurus borealis*) inhabits forests from southern Canada to South America as far as Chile and Argentina, spanning from the Atlantic Coast to the Continental Divide (Shump and Shump 1982; Cryan 2003). During the winter months, red bats are found more commonly south of the Ohio and Missouri River Valleys, predominantly in the states surrounding the Gulf of Mexico (Kurta and Lehr 1995; Cryan 2003). Red bats are a migratory species, with reports such as occurrence records from ships out at sea and observations throughout autumn of "great flights of reds during the whole day" (Mearns 1898; Howel 1908; Thomas 1921; Carter 1950; Findley and Jones 1964). The extent of their migration is not fully known, with records of the northern extent of their winter range coming mostly from museum collections (Cryan 2003). Males are more common in the northern reaches of their winter distribution than are females (Davis and Lidicker, 1956; LaVal and LaVal 1979; Padget and Rose 1991; Cryan 2003; Mormann and Robbins 2006).

Red bats are named for the rusty to brick red pelage of males that differs from the dull brown fur of the females. They also possess a furred uropatagium (tail membrane), characteristic of Lasiurines. Females average 2.3 young per year, with as many as 5 being found with one mother (Shump and Shump 1982). Red bats are insectivorous and achieve body masses of 7 to 13 grams (Shump and Shump 1982; Whitaker et al. 1997).

Population data are lacking for red bats owing to their non-colonial roosting habits. Unlike the majority of other North American bat species that colonially roost in caves and manmade structures (houses, bridges, etc.), red bats roost solitarily within the foliage in forests and small patches of trees throughout their range. Species known to use

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trees throughout the year are known as 'tree bats' (Griffin 1970), and include eight North American species (Carter and Menzel 2007). Recent information suggests that populations of red bats have declined over the past several decades, making studies into factors that influence their habitat and behaviors important for conservation needs (Carter et al. 2003; Winhold et al. 2008).

Summer foraging habitat studies by Hutchinson and Lacki (2000) determined that red bats in mixed mesophytic forests foraged over water more than expected. However, Furlonger (1987) found that red bats in southwestern Ontario were active over terrestrial habitats (fields and forests) significantly more than over aquatic habitats (ponds and streams) (Elmore 2005). No winter foraging habitat studies have been reported, but digestive tracts of red bats from the Great Dismal Swamp region (southeastern Virginia, northeastern North Carolina) during winter were shown to consist of 90% lepidoptera and diptera (Whitaker et al. 1997). Dietary tracts and fecal analyses from bats captured in southern Missouri during the winter contained predominately lepidoptera, diptera, and coleoptera (Dunbar et al. 2007).

Winter Habits

The current assumption is that tree bats require mild winter climates to permit foraging activity, and exhibit short-duration bouts of torpor (Cryan and Veilleux 2007; Dunbar et al. 2007). Winter habits of red bats have recently attracted research interest (Whitaker et al. 1997; Saugey et al. 1998; Moorman et al. 1999; Boyles et al. 2003; Cryan 2003; Dunbar and Tomasi 2006; Mormann and Robbins 2006; Scesny 2006; Flinn 2009) mainly due to their unique habit of roosting under the leaf litter of forests. This leaf roosting habit was discovered after noticing bats arousing and flying up from the ground during prescribed fires (Saugey et al. 1998).

In southern Missouri red bats winter roost sites were located on southern facing slopes significantly more often than random expectations (Mormann and Robbins 2006). In that study, bats selected eastern red cedars as winter tree roosts in higher proportion to availability and in deeper leaf litter than predicted by chance. Flinn's (2009) study in a mixed-pine deciduous forest during the winter found bats to roost on higher elevations on southern facing slopes, but chose oak trees for roosting more often compared to the available pine roosts.   The winter roosting behavior of red bats is thermally-dependent. When temperatures approach or go below $0^{o}C$, red bats and the related Seminole bats abandon tree roosts in favor of leaf litter which provides a more suitable and stable microclimate beneficial for energy conservation (Hutchinson and Lacki 2000; Mager and Nelson 2001; Mormann and Robbins 2006; Hein et al. 2008; Flinn 2009).

During cold temperatures bats go into hibernation, a form of torpor, thereby conserving body heat and reducing stress on their thermoregulation requirements (Davis and Lidicker 1956; Davis 1970; Genound 1993). Torpor refers to any controlled lowering of body temperature and metabolic rate below levels maintained by resting euthermic individuals (Barclay et al. 2001). When red bats go into torpor they envelop their ventral surface and wings with their uropatagium, thereby insulating themselves (as seen in Davis and Reite 1967). The selection of winter roosts contributes to greater energy savings during arousals from torpor by allowing opportunities for passive rewarming (Geiser et al. 2004; Dunbar and Tomasi 2006). This passive rewarming can decrease energy needed for arousal, but reaction times to direct stimuli can be delayed due to the animal not having easily accessible energy.

Prescribed Fire

Concerns about the impact of fire on bat communities have been raised in recent papers (Carter et al. 2002; Keyser and Ford 2005; Boyles and Aubrey 2006). Prescribed burning is implemented on forests throughout the U.S. to mitigate conditions causing catastrophic wildfires, without affecting normal functions in fire-adapted ecosystems (Monroe and Converse 2006). Unlike other types of hardwood forests, such as northern hardwoods and bottomland hardwoods, many oak-dominated forests have relatively short fire return intervals (4 to 30 years) over most of the region (Frost 1998; Keyser and Ford 2002). Management of forests for timber production and habitat conservation has relied heavily on the implementation of prescribed fires. Managers of forests for timber production have embraced the benefits of fire for promoting growth of profitable lumber species such as walnut, oak, and pine. Unfortunately the availability of reliable data upon which forest managers can make decisions regarding aspects of biological diversity is limited, particularly with silvicultural prescriptions and landscape-habitat relationships (Miller et al. 2003).

With the multitude of benefits that fires provide, fire ecology has become a multifaceted branch of environmental research. Canopy reduction, suppression of exotic and invasive species (honeysuckle, multifloral rose), reduction of understory growth/clutter, propagation of seeds that need fire (lodgepole pine) in order to germinate, and wildfire-fuel-reduction are positively influenced by fires in a healthy ecosystem. Also, the economic importance of wood products cannot be overlooked when addressing ecological issues related to forests. Because fire was historically thought to be destructive to ecosystems, it was fervently suppressed on America's public and private lands into the 1980s. It was not until researchers recognized that burning increased

biodiversity that the 'Smokey Bear' philosophies were retooled to encourage the use of fire as a management tool (Johnson and Hale 2000).

The beneficial effects of fire on fire-dependent habitats usually compensates for any potential losses, such as roost trees and vegetation (Vogl 1973). Because fire was historically prevalent across the eastern landscape, wildlife evolved adaptations to fire in order to survive (Komarek 1974; Brennan 1998; Van Lear and Harlow 2002). Research involving "burn vs. non-burn" treatments has shown an increased diversity over time of plants and animals on areas that have been burned (Wright and Bailey 1982). Forest communities with an absence of fire or other destructive forces have shown a decrease in bird niche diversity and carrying capacity (Marshall 1963; Wood and Niles 1978). Mammalian and ornithological life histories have certain aspects that occur at only particular times of the year, spring being very crucial to one-time or once-a-year breeders. In addition to seasonal timing of fires, population responses of small mammals are also related to fire uniformity, intensity, size, and duration of the burn (Buech et al. 1977; Wright and Bailey 1982).

Winter burns are generally cooler and cause minimal damage to canopy trees but are not as effective at removing undesirable vegetation as late season summer burns (Van Lear and Waldrop 1989). Cool season fires are characterized by being less intense, patchier, and producing a greater density of understory plants after one year post fire than late dry season burns (Monroe and Converse 2006). Low intensity fires are usually characterized by flame heights less than 0.6 m, consuming only leaf litter and small woody debris, which causes little, if any, overstory mortality (Brose et al. 2005).

Fires may cause direct mortality of flora and fauna, but this affect is offset by increased amount and quality of food and cover for most species (Vogl 1973; Monroe

and Converse 2006). For example, closed canopy forest characterized by high stem density and little to no understory development is least desirable for bat species (Thomas 1988; Humes 1999).

Although fires help in many ways, it does introduce short term detrimental affects on plants and animals that are in the path of an oncoming fire. 'Escape responses' of animals to oncoming fires have been a topic of interest for some time (Howard et. al 1959). Predominantly, animals have been shown to realize the immediate danger and avoid it altogether, utilizing basic survival instincts to flee (Geluso 1986; Withgott and Amlaner 1996). Frogs have been shown to respond to certain cues produced by fires. Reed frogs (*Hyperolius nitidulus*) reacted strongly to the sound recording of a fire, exhibiting behaviors such as raising their heads, scanning their surroundings, and then jumping into adjacent vegetation in the opposite direction from which the sound originated (Grafe et al. 2002). Animals are particularly susceptible to fire when they are impaired or non-mobile as with altricial young (i.e., mouse pups, bird nestlings). The negative effects on these groups of animals can be resolved by timing burn plans so they do not occur during parturition or when vulnerable neonates or hatchlings are present.

Red Bat Response to Prescribed Fire

Due to the prevalence of winter prescribed fires conducted by the Missouri Department of Conservation (MDC) and the rarity of winter fires occurring throughout the evolutionary history of red bats, they are thought to be a species that may be harmed because of their leaf roosting habits. During a fire in Arkansas, red bats were often observed on the ground still in a state of near torpor while attempting to crawl or fly (Saugey 1989); they have been observed flying from fires in Missouri (Mormann 2005),

West Virginia (Rodrigue et al. 2001), South Carolina (Moorman et al. 1999), and other southeastern states.

Scesny (2006) tested red bat responses (first response and arousal) from torpor at 5 C to stimuli associated with prescribed fires: smoke from burning leaves and sound recorded from an actual fire. The smoke stimulus prompted bats to arouse, whereas controls and the sound of fire did not illicit arousal. The latency to exhibit a first response and arouse from torpor during the playing of the fire sound plus smoke stimulus was shorter than for the smoke stimulus alone. The fire sound appeared to act as a catalyst to speed up reactions during trials. This experiment emphasized the importance of smoke for torpid bats' awareness to fire, however lab conditions did not fully encompass the whole range of parameters that are associated with actual wild or prescribed fires. In nature, smoke is more variable than what was presented in the environmental chambers.

Prescribed fires are set during the winter at a varying degree of temperatures and ambient weather conditions throughout Missouri's public and private lands. The objective of my study was to determine how variations in ambient weather conditions influenced the emergency roost switching of torpid red bats to fire stimuli by recording the latency durations of first response, arousal, and flight. This study should provide guidelines for winter fire management as it relates to reducing any direct negative impact on resident eastern red bats.

METHODS AND MATERIALS

Study Area

Research was conducted from 1 December 2007 to 27 March 2008 in Carter County, Missouri on Peck Ranch Conservation Area (PRCA). This 9,327 ha area is managed by the Missouri Department of Conservation for short leaf pine regeneration and glade restoration. It has a hilly topography with a mixture of pine and hardwood trees. Fires are conducted in units that range in size from 95 ha to 660 ha during the winter and early spring to enhance woodland and glade communities by suppressing invading understory plants and reducing litter depths (Stevenson 2007). Prescribed burning was initiated for each unit between 1989 and 2001 with fire intervals for all units ranging from 2-6 years (Stevenson 2007). Bats are active at this area during the winter when daily temperatures are above 10°C (Mormann and Robbins 2006; Flinn 2009).

Field Lab (Burn Arena)

The burn arena (Fig. 1) was located in an open grass field at the Missouri Forest Ecosystems Projects house located on PRCA. This field is at the bottom of a valley with forested hills directly to the east and west. A rectangular area (2.5 m X 1.5 m) in the middle of the field was leveled and cleared to eliminate grass. Next, it was bordered with plastic edging and sand was spread over the bare dirt. Leaf litter found on PRCA was placed (ca. 10 cm depth) over the sand to emulate forest ground cover. Three circular cone cages were placed 0.2 m apart in a line down the middle of the area and were held in place by stakes. Two troughs (2.5 m X 1.2 m X 0.25 m; 2 m X 0.5 m X 0.25 m) composed of expanded metal and square tubing were positioned outside of the cleared area at a distance ca. 3 m. During trials, the troughs were filled with leaves ca. 20 cm and covered with a sheet of expanded metal to contain burning leaves. All crew members had level 1 fire training issued by MDC and had access to rakes and a supply of water.

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Recording Equipment

During burn trials, bats were monitored and recorded with the aid of surveillance cameras. Each camera was connected by a 30 m coaxial cable to a video processor (Everplex 8BDX). The processor was connected to a black/white video monitor (Tatung TBM-1203) and a time lapse video cassette recorder (Mitsubishi HS-1280U). Recording equipment was stationed on a table 10 m from the fire where one observer stayed to ensure all equipment was operational. A Kestrel 4500 Pocket Weather Tracker was placed on a 1.5 m tall wind vane 10 m to the east of the burn arena to record temperature (^{o}C), relative humidity (%), and wind speed (km/h) every minute from the time bats were placed into cages until the end of each burn trial.

Captures

Bats were captured via 2 tiered 6 m, 9 m, or 12 m mist nets (Avinet, Dryden, New York) placed over service roads and ponds located on high elevation areas throughout PRCA as temperatures generally remained higher in these areas than in low elevation valleys. Nets placed in flyways were positioned under "false canopies" constructed from 12 m X 2.5 m plastic mesh strung from two 10 m poles. These served to funnel bats into areas where nets were placed. Nets were administered from 1630 to 2100 or until no activity from flying bats was observed for >1 hr. Bats were identified to species, sexed, weighed, measured for forearm length, and visually examined for overall health. A net night was defined as one mist net opened into the capture position for the evening's activities (see Saugey et al. 1989).

Field Trials

Weather forecasts were obtained from Intellicast.com from a weather station in Van Buren, MO, 35 km east of PRCA. When temperatures were above 8°C and the next

morning had a probability of precipitation <80 %, a field trial was scheduled. These

conditions were chosen to ensure a high probability of capture success, and because

MDC rarely conducts prescribed fires during precipitation. The number of video cameras

(3) limited the number of bats retained overnight for field trials. Bats caught during a

night's netting activity were transported in separate cloth bags to the field lab, where they

were removed from the bags and placed into individual cages. The following morning,

cages were examined and roosting positions were classified as either Perched (hanging

from the cage) or Prone (underneath leaf litter). Bats in the Prone position were

considered to be in torpor and their cages were removed in order to locate them under the

leaves. Although this was rather moderate disturbance, preliminary work by Scesny

(2006) on red bat arousal due to constant physical agitation at 5°C took $50 - 70$ min to

illicit response. Next, video and recording equipment were set up and cameras positioned

to frame bats for optimal viewing (i.e. head visible) throughout the trial. Time,

temperature, and wind direction were recorded at the onset of each trial. A drip torch

provided by MDC was used to light the trough of leaves that corresponded to a heading

fire (flames and smoke going toward the fuel being consumed and thus toward the bat) in

order to provide the greatest amount of smoke exposure to the bats. Fire was maintained

in the covered trough by supplying leaves to the trough until the end of the trial. If the

wind direction changed during a trial, the trough opposite of the one burning would be lit.

This action was implemented only after the first trough's fire had stopped burning,

therefore both troughs were not lit at the same time. Bats were continually monitored

until they had flown or the fire had been burning for one hour, at which time the trial was

terminated. The fire was then extinguished and the area was monitored to prevent

incidental flare ups.

Behavior

Scesny (2005) defined first response "as any movement or observed increase in respiration" from the onset of the trial, and arousal "as movement from one location to another." Burn trial videos were viewed to time latency to first response and latency to arousal behaviors to the onset of the fire. When a behavior was observed on the video, the start of the action was marked and subtracted from the onset of the fire to produce latency durations. The additional behavior that was measured during field trials was latency to flight, herein defined as the time from the onset of the fire until the bat flew. Bats regularly aroused and crawled out of the video frame where they could no longer be viewed. Therefore, flight latency times were recorded by visual observations of bats flying from the ground.

Protocols followed guidelines for animal use in research and were approved by the Missouri State University Institutional Animal Care and Use Committee (Protocol # 2009A: 15 January 2009).

Data Analyses

Data for temperature, wind speed, and relative humidity obtained from the weather logger for each trial were separated into 3 time periods: (1) 2200 at night of capture through one minute before sunrise, (2) sunrise through one minute before the onset of the trial, and (3) onset until the trial ended. Latency values of all three observed behaviors were viewed against each separate time period's weather data and examined for associations among variables. A Pearson's product moment correlation (r) for all correlations were performed on Minitab statistical software (Minitab Inc., State College, Pennsylvania) to ascertain the strength of relationships. I used $\alpha = 0.05$ for indicating significance in correlation values.

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Smoke

A carbon monoxide (CO) monitor with two sensors (Sixth Sense, Inc. Eco-Sense 2e electrochemical sensors with a custom electronics signal conditioning board) (Dickinson et al. 2009) was used during one field trial. Sensors were placed on the ground in the burn arena between the bats and sampled every 10 sec. The CO sensor was not available for other field trials.

Additionally, the CO monitor was used in the same environmental chamber as used in Scesny's (2006) red bat lab arousal tests to quantify the CO provided by the earlier laboratory experiments. The sensors were placed in the same position as bats during trials, and trials without bats were conducted following methods described by Scesny (2006). Data were calibrated using Microsoft 2007 Excel.

Figure 1. Burn arena for field trials complete with three circular cone cages placed on top of emulated forest ground cover with two leaf troughs positioned to the side.

RESULTS

Captures

From 1 December 2007 to 28 March 2008, bats were netted on 24 nights with a total of 67 net nights at six separate locations throughout PRCA. Eleven nights produced no captures. All bats were caught within 1.5 hours of sunset. Eighty-four bats of four different species were captured: *Lasiurus borealis*, *Lasionycteris noctivagans*, *Myotis septentrionalis*, and *Nycticeius humeralis* (Table 1). *Myotis* and *Nycticeius* were only caught in March, *Lasionycteris* bats were caught in all months except December, and red bats were captured throughout the whole season. Males of three species were caught more than females (Table 2).

Burn Trials

Twenty-three red bats (22 males, 1 female) were tested for behavioral responses to the prescribed fire stimulus in nine separate field trials (Table 3). Four bats that were to be tested were not included in the analyses because one bat aroused and flew before the onset of a field trial (7 Jan 2008), and all three bats of another scheduled trial escaped the night prior due to cage disturbance by a raccoon (*Procyon lotor*). Out of the 22 male bats that went through fire trials, 17 were in the Prone position, and five bats were in the Perched position on the side of the cage. Due to a malfunction with recording equipment during one field trial (1 March 2008), first response and arousal behavior values were not recorded for two bats in the Prone position. Of the Prone bats, 14 exhibited a first response during trials, and 13 aroused and had a flight response. All five Perched bats exhibited each behavior.

Behavior: Males. First response, arousal, and flight latency values versus temperature, wind speed, and relative humidity of all three time periods are presented in

Tables 4, 5, and 6 respectively. Latency to first response, arousal, and flight response were significantly negatively correlated to temperature during all three Time Periods (Tables 4, 5, and 6, respectively). First response and arousal latency at Time Periods 2 and 3 were correlated to wind speed (Tables 4 and 5), whereas flight response latency was significantly negatively correlated to wind speed during all three Time Periods (Table 6). Correlation graphs depicting significant Prone behaviors of male bats for first response, arousal, and flight latency versus weather parameters measured for the three different time periods are described below and shown in Figures 2-18.

Mass of bats was not significantly correlated with latency behaviors. Perched positions were observed during the month of March only; however latency of behavior values of Perched bats were not significantly correlated with any independent variable measured.

First Response. Pearson product moment correlation indicates a significant negative association between first response latency values and temperatures at Time Period 1 ($r = -0.528$, $r^2 = 0.279$, d.f. = 13, $p < 0.043$) (Fig. 2), Time Period 2 ($r = -0.764$, $r^2 = 0.584$, d.f. = 13, $p = 0.001$) (Fig. 3), and Time Period 3 ($r = -0.779$, $r^2 = 0.607$, d.f. = 13, $p = 0.001$) (Fig. 4). There is also a significant negative association between first response latency values and wind speeds at Time Period 2 ($r = -0.844$, $r^2 = 0.712$, d.f. = 13, $p < 0.0005$) (Fig. 5), and Time Period 3 ($r = -0.912$, $r^2 = 0.833$, d.f. = 13, $p < 0.0005$) (Fig. 6). A significant positive association between relative humidity and first response at Time Period 3was observed($r = 0.598$, $r^2 = 0.358$, d.f. =13, $p < 0.05$) (Fig. 7), but no other significant correlation was found between relative humidity and any latency response.

Arousal. Arousal latency values compared to temperature indicates significant negative associations between decreasing arousal latency values and increasing temperatures at Time Period 2 ($r = -0.839$, $r^2 = 0.704$, d.f. = 13, $p < 0.0005$) (Fig. 8), and Time Period 3 ($r = -0.855$, $r^2 = 0.731$, d.f. = 13, $p < 0.0005$) (Fig. 9). Wind speeds compared to arousal latencies showed significant correlations at Time Period 2 ($r = -0.877$, $r^2 = 0.770$, d.f. = 13, $p < 0.0005$) (Fig. 10), and Time Period 3 ($r = -0.957$, $r^2 = 0.915$, d.f. = 13, $p < 0.0005$) (Fig. 11).

Flight. Latency to flight in red bats compared to temperature was significantly negatively correlated between all three Time Periods: (**1**) ($r = -0.794$, $r^2 = 0.630$, d.f. = 15, $p < 0.0005$) (Fig. 12), (**2**) ($r = -0.883$, $r^2 = 0.779$, d.f. = 15, $p < 0.0005$) (Fig. 13), and (**3**) ($r = -0.856$, $r^2 = 0.732$, d.f. = 15, $p < 0.0005$) (Fig. 14). Flight latencies compared to wind speed at all three Time Periods indicates a significant negative association as well: (**1**) ($r = -0.613$, $r^2 = 0.375$, d.f. = 14, $p < 0.05$) (Fig. 15), (**2**) ($r = -0.831$, $r^2 = 0.691$, d.f. = 15, $p < 0.0005$) (Fig. 16), and (**3**) ($r = -0.797$, $r^2 = 0.636$, d.f. = 15, $p < 0.0005$) (Fig. 17).

Behavior: Female. On 22 March 2008 a female red bat was tested for behavioral responses. During the trial, the temperature average was 5.6°C, the wind speed averaged 3.3 km/h, and the relative humidity average was 82.4 %. The bat exhibited a first response 1:19 min after the fire started, and arousal latency was 7:36 min, but it exhibited no flight response. The bat crawled ca. 0.5 m away from its prone position to another pile of leaves and remained there during the rest of the trial.

Smoke

Throughout the field burn trial of 28 Jan 2008, CO was measured with a smoke analyzer and CO averaged 1.51 PPM, with a maximum exposure of 40 PPM. First response latency values of all three bats tested were 11:18, 11:44, and 11:39 min.

Arousal latency values were 22:52, 23:11, and 28:07 min. Latency to flight values were 38, 40, and 42 min.

Concentration of CO measured in the environmental chambers fluctuated among trials (n=3). Average amount of CO was 135.08, 99.40, and 57.32 PPM, sequentially. Maximum exposure of each trial was 375, 291, and 184 PPM, respectively.

Table 1. Species captures for winter 2007-2008 at Peck Ranch Conservation Area.

Date	Common Name	# Captured
01 Dec 2007	Eastern Red Bat	5
18 Dec 2007	Eastern Red Bat	4
05 Jan 2008	Eastern Red Bat	1
06 Jan 2008	Eastern Red Bat	7
	Silver-Haired Bat	1
27 Jan 2008	Eastern Red Bat	3
29 Feb 2008	Eastern Red Bat	5
01 Mar 2008	Eastern Red Bat	8
	Silver-Haired Bat	1
12 Mar 2008	Eastern Red Bat	12
	Silver-Haired Bat	1
20 Mar 2008	Eastern Red Bat	5
21 Mar 2008	Eastern Red Bat	6
	Silver-Haired Bat	1
25 Mar 2008	Eastern Red Bat	5
	Evening Bat	2
	Northern Myotis	1
26 Mar 2008	Eastern Red Bat	9
	Silver-Haired Bat	3
	Northern Myotis	1
27 Mar 2008	Eastern Red Bat	2
	Northern Myotis	1

Table 2. Number of captures for December 2007 through March 2008 at Peck Ranch
Conservation Area.

Common Name	Species	Male	Female	Total
Eastern Red Bat	*Lasiurus borealis*	71	1	72
Silver-Haired Bat	*Lasionycteris noctivagans*	5	2	7
Northern Myotis	*Myotis septentrionalis*	2	1	3
Evening Bat	*Nycticeius humeralis*	1	1	2
	Total	79	5	84

Table 3. Number of bats tested during each burn trial at Peck Ranch Conservation Area.

Date	Trial #	# of Bats
19 Dec 2007	1	3
06 Jan 2008	2	1
07 Jan 2008	3	1*
28 Jan 2008	4	3
01 Mar 2008	5	3
02 Mar 2008	6	3
21 Mar 2008	7	3
22 Mar 2008	8	3
27 Mar 2008	9	3
Total		23

* Indicates trial where bat flew before the onset of burn trial.

Table 4. Correlation coefficients and associated *p* values of latency to first response vs. ambient weather parameters. Values are for each time period: 1 = Night before burn trial (2200) to one minute before sunrise, 2 = Sunrise to one minute before onset of trial, 3 = Onset of burn trial to end of burn trial. For all, n = 15 (except Time Period 1 wind speed (n=14)).

Time Period	Temperature		Wind		Relative Humidity	
	r	*p*	*r*	*p*	*r*	*p*
1	-0.528	*0.043*	-0.362	0.204	0.357	0.191
2	-0.764	*0.001*	-0.844	*0.000*	0.453	0.090
3	-0.779	*0.001*	-0.912	*0.000*	0.598	*0.018*

** Indicates significance at $p < 0.05$, d.f. = (n-2).

Table 5. Correlation coefficients and associated *p* values for arousal latency vs. ambient weather parameters. Values are for each time period: 1 = Night before burn trial (2200) to one minute before sunrise, 2 = Sunrise to one minute before onset of trial, 3 = Onset of burn trial to end of burn trial. For all, n = 15 (except Time Period 1 wind speed (n=14)).

Time Period	Temperature		Wind		Relative Humidity	
	r	*p*	*r*	*p*	*r*	*p*
1	-0.620	*0.014*	-0.480	0.083	0.254	0.362
2	-0.839	*0.000*	-0.877	*0.000*	0.381	0.161
3	-0.855	*0.000*	-0.957	*0.000*	0.509	0.053

** Indicates significance at $p < 0.05$, d.f. = (n-2).

Table 6. Correlation coefficients and associated *p* values for flight latency vs. ambient weather parameters. Values are for each time period: 1 = Night before burn trial (2200) to one minute before sunrise, 2 = Sunrise to one minute before onset of trial, 3 = Onset of burn trial to end of burn trial. For all, n = 17 (except Time Period 1 wind speed (n=16)).

Time Period	Temperature		Wind		Relative Humidity	
	r	*p*	*r*	*p*	*r*	*p*
1	-0.794	*0.000*	-0.613	*0.012*	0.288	0.262
2	-0.883	*0.000*	-0.831	*0.000*	0.159	0.542
3	-0.856	*0.000*	-0.797	*0.000*	0.062	0.813

** Indicates significance at $p < 0.05$, d.f. = (n-2).
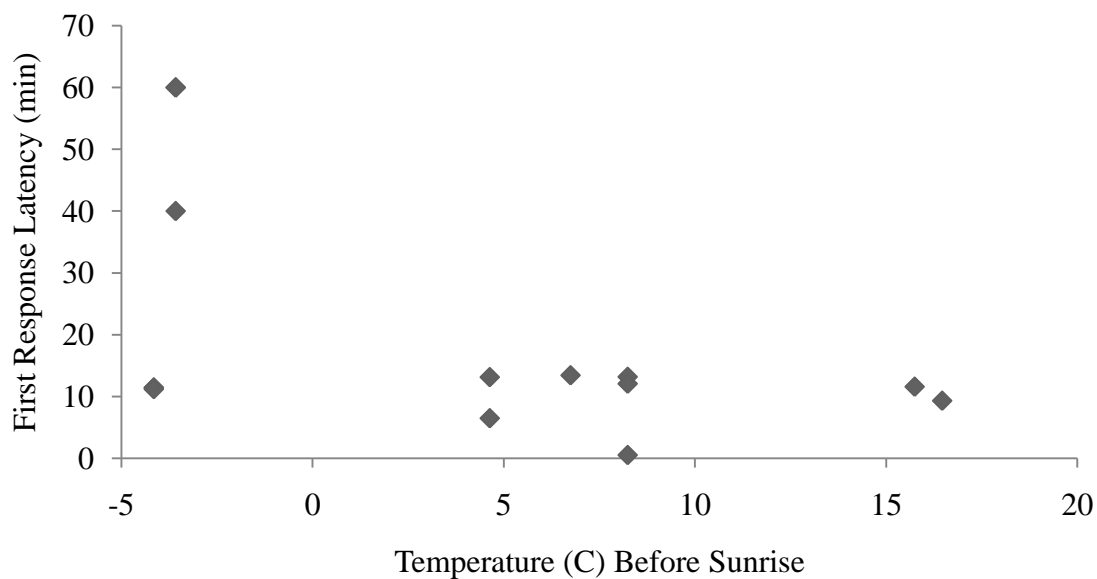
Figure 2. First response latency versus temperature at Time Period 1 (2200 through one minute before sunrise). r = -0.528, $p < 0.05$.
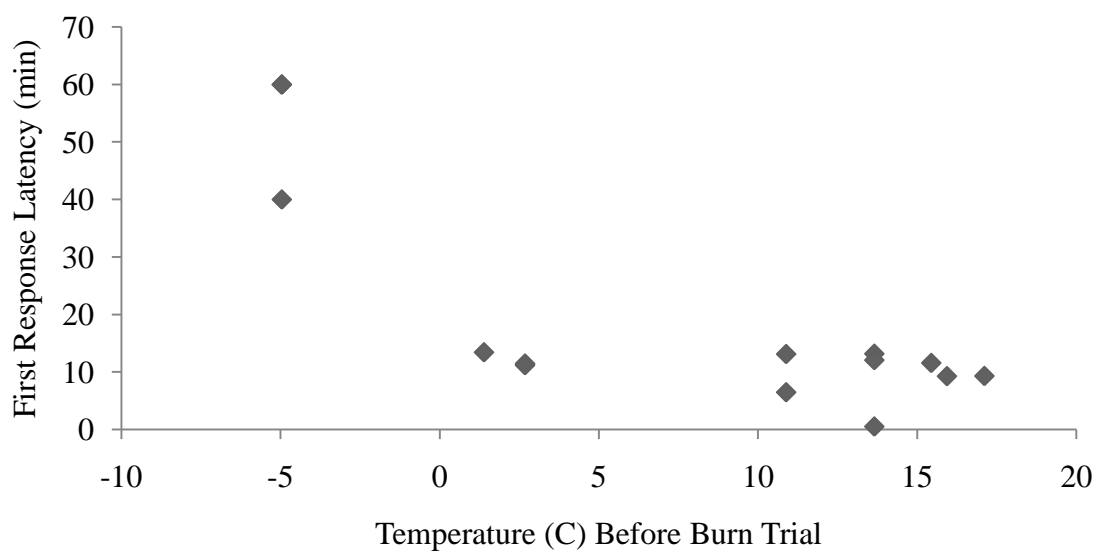
Figure 3. First response latency versus temperature at Time Period 2 (Sunrise through one minute before onset of trial). r = -0.764, $p = 0.001$.
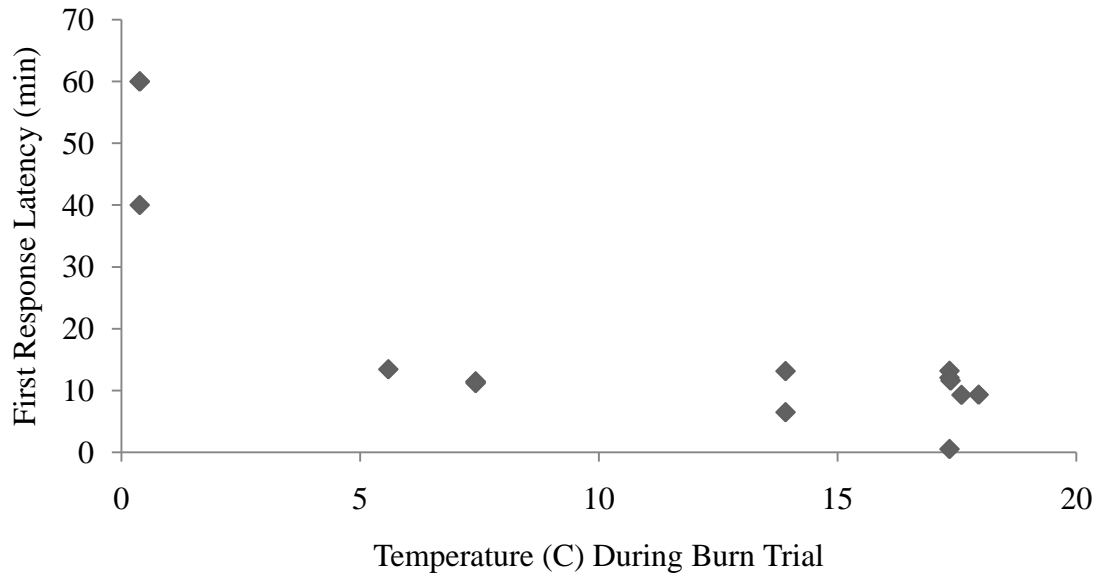
Figure 4. First response latency versus temperature at Time Period 3 (Onset through end of trial). r = -0.779, *p* = 0.001.
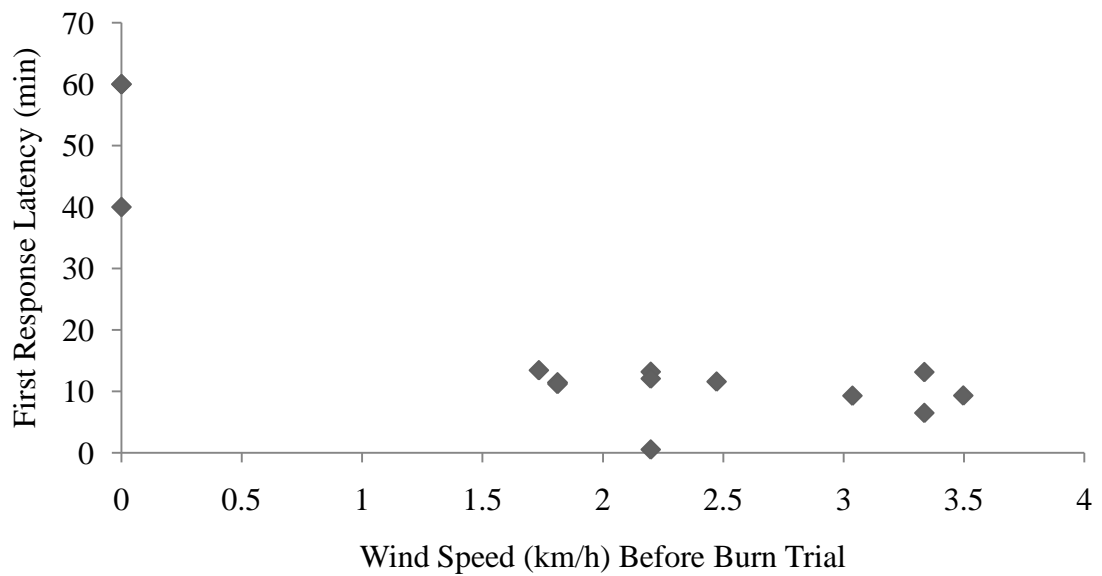
Figure 5. First response latency versus wind speed at Time Period 2. r = -0.844, *p* < 0.0005.
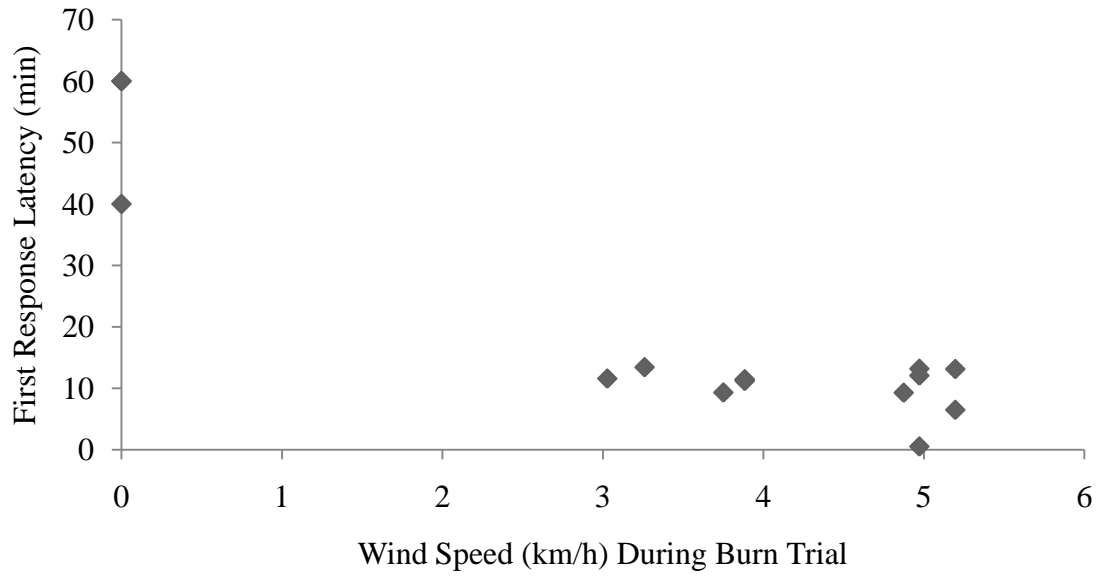
Figure 6. First response latency versus wind speed at Time Period 3. r = -0.912, *p* < 0.0005.
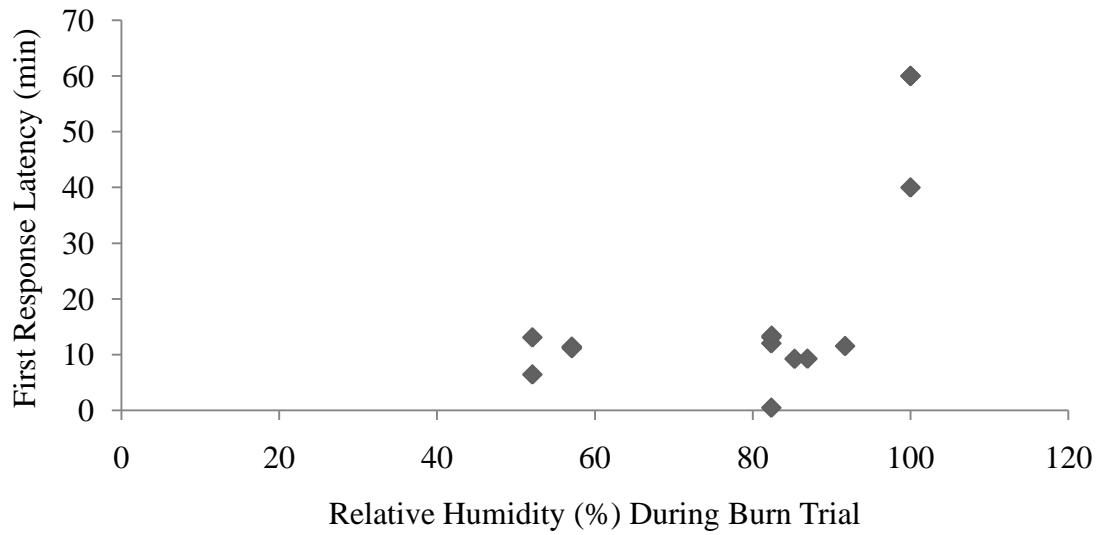
Figure 7. First response latency versus relative humidity at Time Period 3. r = 0.598, *p* < 0.05.
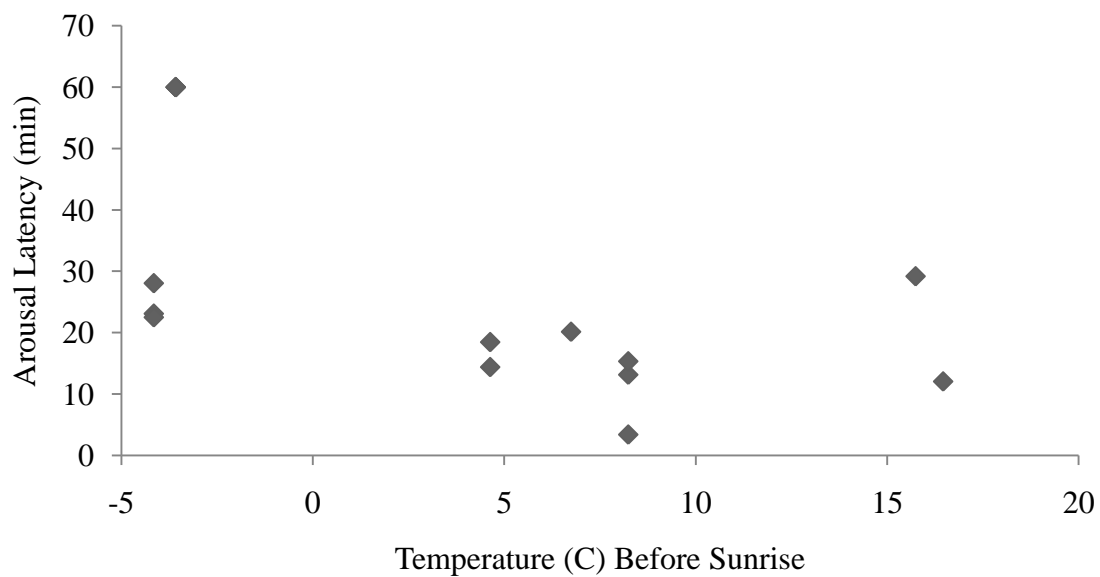
Figure 8. Arousal latency versus temperature at Time Period 1. r = -0.620, $p < 0.05$.
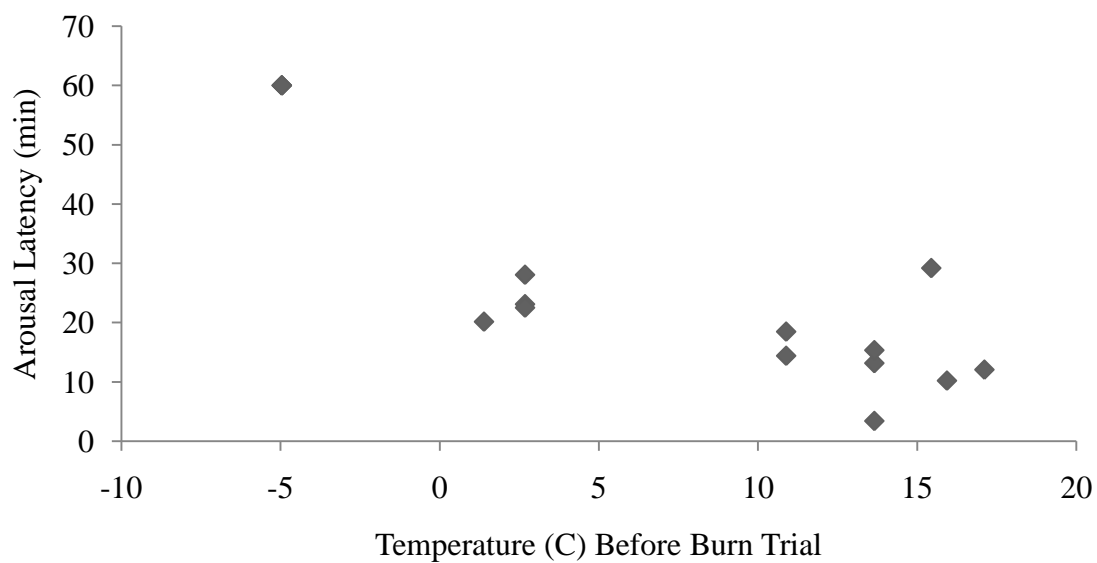
Figure 9. Arousal latency versus temperature at Time Period 2. r = -0.839, $p < 0.0005$.
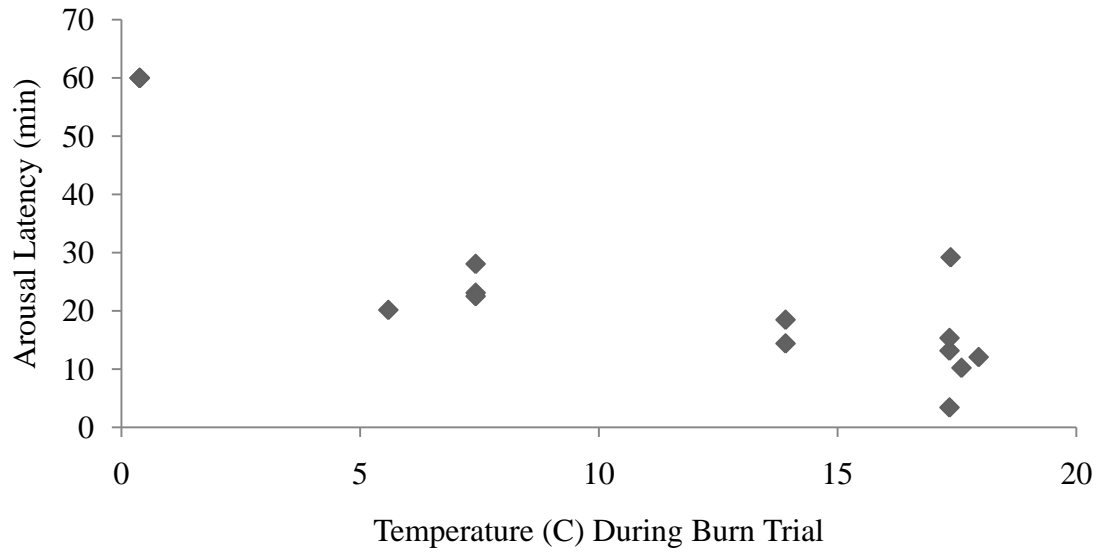
Figure 10. Arousal latency versus temperature at Time Period 3. r = -0.855, $p < 0.0005$.
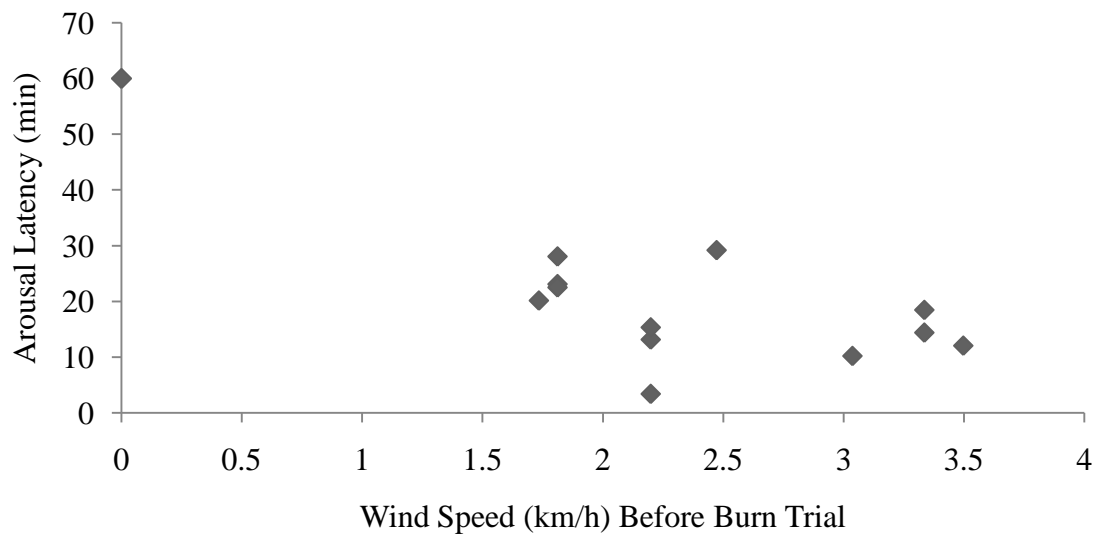
Figure 11. Arousal latency versus wind speed at Time Period 2. r = -0.877, $p < 0.0005$.
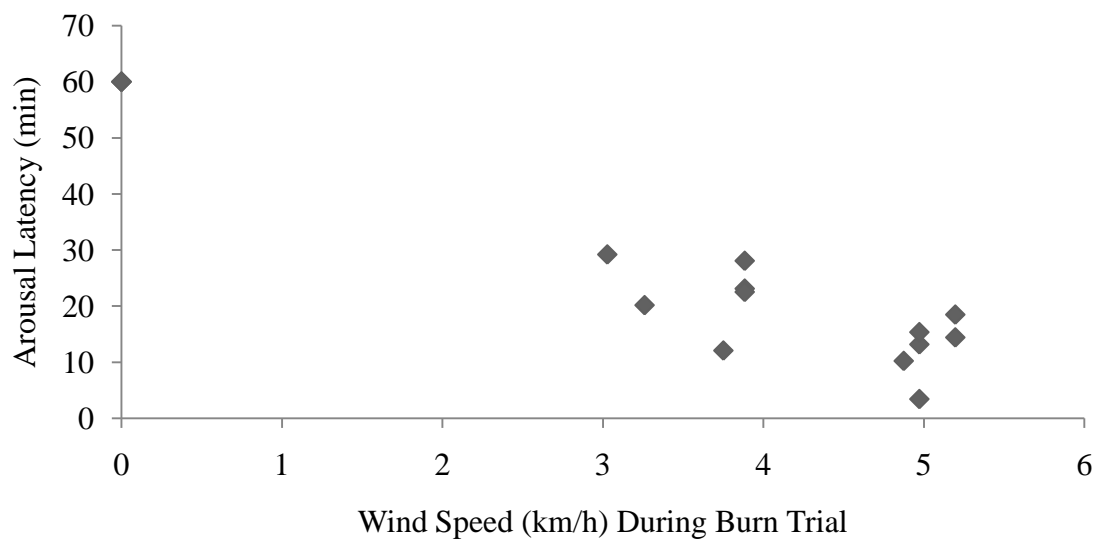
Figure 12. Arousal latency versus wind speed at Time Period 3. r = -0.957, $p < 0.0005$.
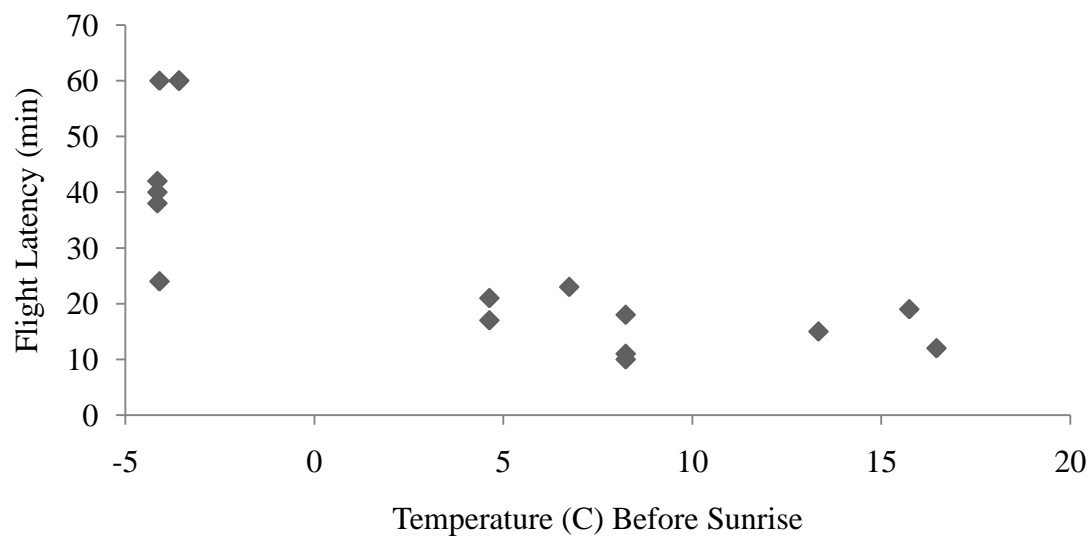
Figure 13. Flight latency versus temperature at Time Period 1. r = -0.794, $p < 0.0005$.
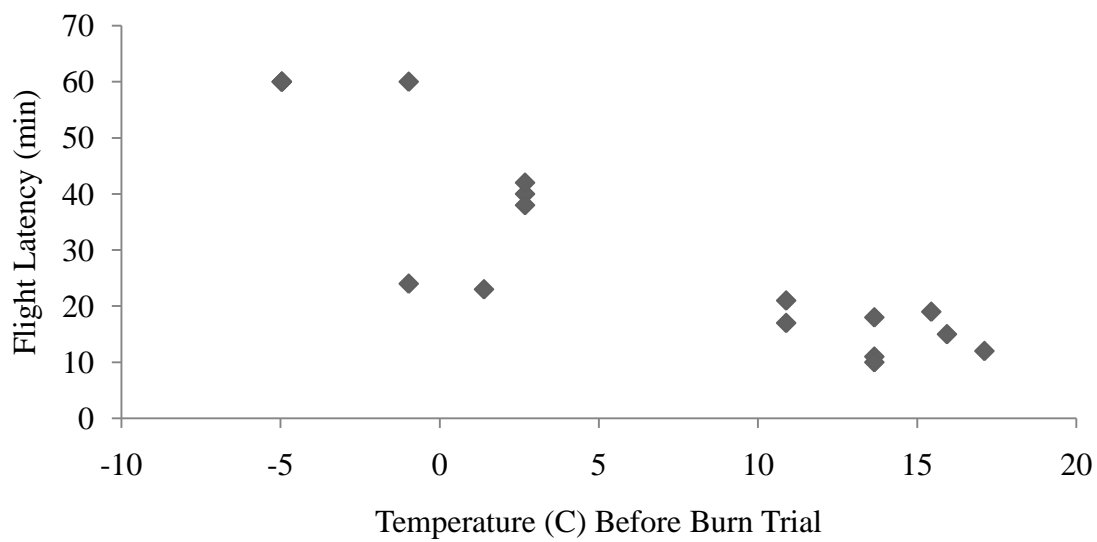
Figure 14. Flight latency versus temperature at Time Period 2. r = -0.883, *p* < 0.0005.
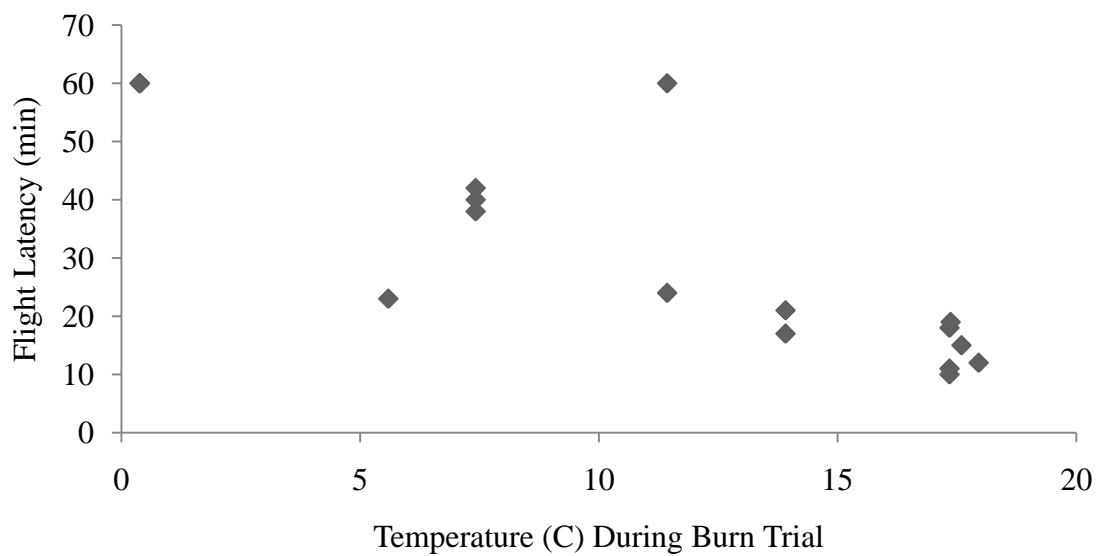
Figure 15. Flight latency versus temperature at Time Period 3. r = -0.856, *p* < 0.0005.
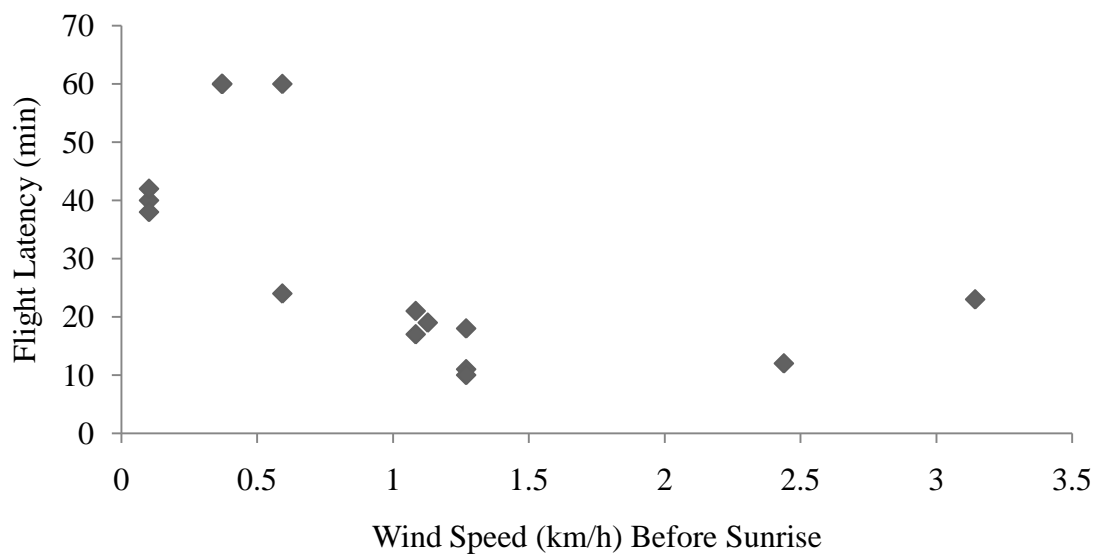
Figure 16. Flight latency versus wind speed at Time Period 1. r = -0.613, *p* < 0.05.
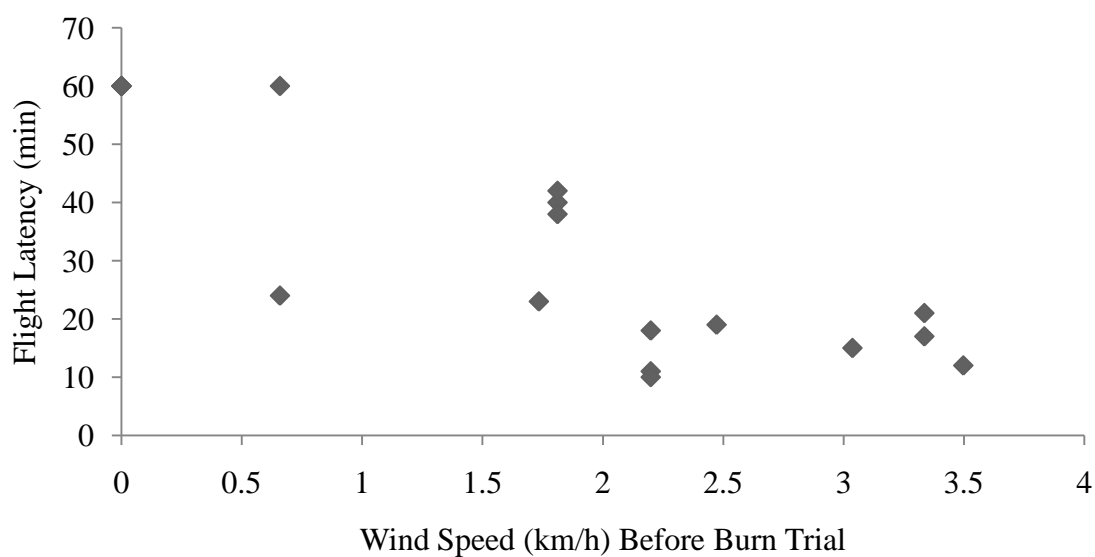
Figure 17. Flight latency versus wind speed at Time Period 2. r = -0.831, *p* < 0.0005.
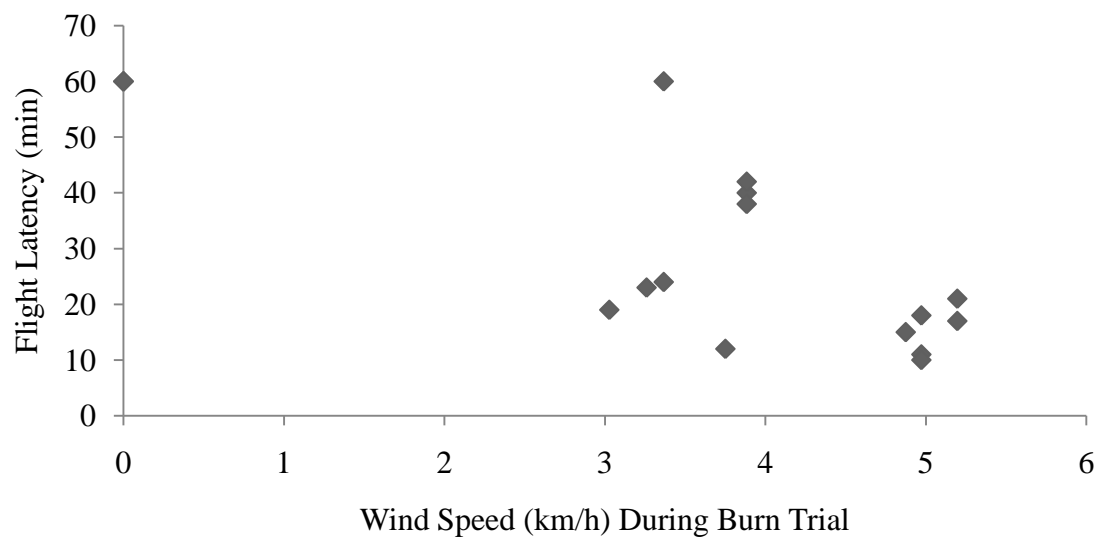
Figure 18. Flight latency versus wind speed at Time Period 3. r = -0.797, $p < 0.0005$.

DISCUSSION

Fire Trials

In the experimental field trials, increased temperature and wind speed were correlated with decreased latencies of response behavior in torpid red bats. Wind during the night prior to a trial had a substantial significant correlation with latency behaviors, and the occurrence of wind propelling smoke over bats during fires confirmed lab findings that smoke greatly increases awareness (Scesny 2006). Relative humidity usually was not significantly associated with latencies to response, but increased humidity was associated with increases in wind speed.

Bats subjected to trials were captured the previous night. I was unable to test bats that had been in torpor for a continuous period (> 1day). However, fires conducted by MDC are performed when conditions are optimal for drying several days prior to a burn. These conditions usually relate to warmer temperatures and conditions that are also favorable for insect activity, thus providing an incentive for bats to be active and forage during the days just before a burn. Although red bats face wide fluctuations of temperatures compared to cavity roosters, they are able to remain in torpor until ambient conditions are appropriate for insect activity (Davis and Reite 1967). Red bats in southwestern Missouri were observed to roost in trees during periods when temperatures exceeded 10° C (Mormann 2005). Bats in tree roosts are able to assess variables in their surroundings more effectively and respond quicker than bats located in leaf roosts (Carter et al. 2002), as exhibited by the Perched bats that all flew during field trials (average flight latency < 14.5 min (n = 5)). No significant behavior correlations of Perched bats to measured variables were observed during my field trials, but this may be contributed to the small sample size.

Inhalation of smoke and heat from an oncoming fire are two major effects that can cause direct mortality of an animal. Bats in the lab showed a decrease in latency of reaction to smoke stimuli compared to any other stimulus (Scesny 2006). During all of my field trials, bats only exhibited a first response after wind blew smoke over the bats. During the field fire trial when CO was monitored (28 Jan 2008), the peak amount of CO measured (40 PPM for one reading) was low compared to the amount encountered during an early-spring prescribed burn of a 185 ha unit (350 to $\leq$ 400 PPM) (Dickinson et al. 2009). My trial's wind speed was 3.9 km/h, which was near the average of all my burn trials (3.6 km/h), and smoke exposure was sporadic, usually lasting less than 1 min. In comparison, peaks and durations of exposure observed in the lab were greater than field measurements, with durations of over 70 PPM lasting longer than 12 min. A higher concentration of CO presumably leads to higher detection probability of fire and therefore would shorten latency of behavioral responses.

Bat flight response latencies from leaf litter roosts seem too long (average = 33 min) to allow for successful escape from a fire in close proximity. If bats were in natural roosting positions with the chance to passively rewarm before the onset of fire, responses may be quicker and more effectual. On 1 March 2008, a male bat did not exhibit a flight response during the field trial and was left at the burn arena. Later that afternoon (1430 h), the bat was observed on top of the leaf litter, breathing heavily, with its back towards the sun. It responded to the noise of my approach and took flight. This observation suggests that the bat may have been in a shallower state of torpor while it was passively rewarming than during the fire trial.

Bats were occasionally observed to arouse and crawl away from their roost locations during burn trials. If a fire is conducted when the top layer of duff is dry but the

lower layers are moist (Klemmedson et al. 1962), or if it is able to find some other

nonflammable refuge, an aroused bat may be able to remain in or move to an area where

the fire would not cause injury or death. Burrowing behaviors were never observed in

burn trials, but this may be an artifact of leaf litter not being deep enough to provide

refuge.

Substrate vibrations, which may contribute to awareness of fire in red bats, were

not measured in this study. Bats that were continuously agitated by physical perturbation

during lab studies took >1 hour to respond (Scesny 2006). However, if a bat has become

aware (exhibited first response) to the smoke of a fire, vibrations may act as an additional

catalyst to decrease latency of other behaviors during prescribed fires.

Carter (2000) commented about the additional threat of aerial predation on bats

seeking refuge during a fire. Observations of hawks at prescribed fires conducting

opportunistic feeding on animals that have fled from open field fires have been reported

(Tewes 1984). When bats flew from my burn arena during trials, they would frequently

go above the tree canopy before I lost sight of them, but no predation was observed. Bats

that are in forested areas may be better protected than those in open field areas.

Additional research could be conducted to measure roost choice of red bats that have

been flushed due to prescribed burning.

Roosting Habitat

Winter foraging activity of bats decreases due to hibernation requirements

(Fleming and Eby 2003; Speakman and Thomas 2003; Hein et al. 2008). Seminole and

red bats have been shown to switch roosts more frequently during warmer weather in

winter, highlighting the increased amount of activity afforded by higher temperatures

(Mormann and Robbins 2006; Hein et al. 2008; Flinn 2009). A southeastern roost aspect,

a characteristic of winter-leaf-roost sites of red and Seminole bats (Mormann and Robbins 2006; Hein et al. 2008; Flinn 2009), may optimize sun exposure and radiant heating for torpid roosting bats especially during cool morning hours (Geiser et al. 2004; Willis and Brigham 2005; Hein et al. 2008).

More than 61% of Seminole bat roosts in South Carolina during winter temperatures <4°C occurred on or near the forest floor (Hein et al. 2008), whereas red bats were shown to select leaf roosts more frequently with decreasing temperatures (Mormann and Robbins 2006; Flinn 2009).   Hein et al. (2008) recommended caution when conducting prescribed burns on days when the previous night's temperature is <4°C to minimize potential direct mortality on bats. Their recommendation was based on bat arousal results from Thomas et al. (1990) indicating that bats may take 30-60 min at 5°C to reach sufficient activity levels for escape. This relatively long latency time agrees with results from Scesny (2006) and from my data; however, I found that although colder temperatures during the night before a fire usually meant cool conditions in the morning, the temperature from sunrise to the onset of the fire had a higher correlation value with latency behaviors than night-before temperatures. Thus, if temperatures before a fire are above 10°C, bats may have a better chance to escape an oncoming fire. For example, temperatures during the night prior to a burn reached 0.8^{o}C (2 March 2008), and all three bats flew within 18 min when the temperature before onset of the fire averaged 13.6^{o}C, suggesting that temperatures before the onset of the burn may have a more significant affect on arousals than temperatures during the previous night.

Sex, Age Differences

Captures of female eastern red bats and Seminole bats during winter are rare, making studies into roosting behaviors gender-biased (Mormann and Robbins 2007; Hein

et al. 2008; Flinn 2009). In the winter of 2005-2006 at PRCA, a female red bat was observed flying from a south-facing aspect roost during a prescribed fire and then roosting in a tree not far from the burn area (J. R. Flinn, L.W. Robbins, and A. A. Scesny personal communication). Although it has been suggested that gender differences likely subside during the non-maternity season (Cryan and Veillux 2007), more research should be conducted to examine roosting of females to prevent management decisions that may only take in to account half of the individuals present.

Juveniles of many animal species use resources differently than do adults, a phenomenon referred to as an 'ontogenetic niche' (Polis 1984; Werner and Gilliam 1984). Sex-segregated groups of red bats observed during autumn were found to be juvenile bats (Mumford 1973). In comparison to adults, high mortalities of juvenile little brown bats (*Myotis lucifugus*) were observed during hibernation, suggesting that the young were not as efficient as adults in acquiring sufficient fat reserves prior to the winter (Davis and Hitchcock 1965; Thomas et al. 1990). Estimating age by degree of ossification in joints of wings is a standard technique for delineating juveniles and adults (Kunz and Anthony 1982). However, this technique is not reliable after the summer in which young are born because ossification occurs rapidly in red bats. Without any banding or visual qualifiers to estimate age, I am unable to verify whether the bats that were tested represented juveniles, adults, or both. Under identical field conditions, individuals responded differently to fire stimuli. Individual variability observed in responses could be attributed to unseen factors I did not measure such as age, physiological health, and/or foraging success the night of capture.

Forest Management

Tiedemann et al. (2000) stated " we maintain that managing for improved health of forests in the Blue Mountains (or any forest) that focuses on prescribed fire as a tool needs to use fire plans that have considered how fire affects all of the important resources and values." This statement is valid in that all components of the forest ecosystem should be managed in the best manner possible; however, the logistics for carrying out an endeavor of this magnitude are difficult. When managing a natural area for habitat-conservation and profit, the best answer may be to manage for patterns and processes that restore and maintain the ecosystem as a whole (Kessler, 1992). The goal of bat biologists dealing with conservation issues is to define and quantify attributes that are of importance to bats (Guldin et al. 2007). Requirements for bat habitat throughout the year need to be quantified, and then interpreted to managers who can satisfy these as well as forest management objectives (harvest, etc.) (Guldin et al. 2007). Understanding how bat assemblages respond to landscape patterns by utilizing the combined efforts of both researchers and managers to overcome gaps in knowledge will be helpful for management planning (Cryan and Veilleux 2007; Wigley et al. 2007). I recommend conducting management practices while keeping detailed records in a standardized database wherein research can be performed on key species and indicators of ecosystem health with complete baseline data sets.

Heterogeneity of habitat is an important factor for several species of animals; thus, conservation of forest areas should not just provide for a single landscape (Campbell et al. 1996). Harvesting that creates a mosaic of patches with different tree densities and ages is likely to satisfy the requirements of more species. Silvicultural methods have different immediate effects on different species of bats that may be

overlooked if the community is studied as a single entity. For example, smaller species are less affected by tree density than large bats because they are more maneuverable (Patriquin and Barclay 2003). Research into the effects of prescribed fire on silver-haired bats (*Lasionycteris noctivagans*) is suggested due to their prevalence in PRCA and because winter fires present a greater risk to their roost structures (trees) than in any other season (Carter et al. 2002; J. R. Flinn personal communication).

Roosting ecology of bats in burn-managed forests is poorly understood. It has been hypothesized that bat species in eastern North America benefit from reducing stem density and the creation of gaps in forest canopy due to management activities (Ford et al. 2005; Menzel et al. 2005; Boyles and Aubrey 2006; Keyser and Ford 2006). Foraging areas and roost trees for cavity roosters increase with forest stand age, the most prevalent of these areas being in old growth (Fisher and Wilkinson 2005). The relationship between number of roosts and the number of bats is important for conservation issues. Evening bats (*Nycticeius humeralis*), a tree-cavity roosting species, were shown to exclusively select roosts located in burned areas in southwestern Missouri (Boyles and Aubrey 2006). In burn units, a significantly greater amount of sunlight in June through September was measured and there were a higher proportion of dead trees to live. Both of these factors contribute to suitable roosting sites with appropriate microclimate specifications (Boyles and Aubrey 2006).

Bats may use clearcuts for foraging, with the availability of suitable roosts likely being the limiting factor for persistence of bat populations; clearcuts without trees do not provide roosting habitat and hence will not likely support resident bat populations. Burned stands within newly-created regeneration areas provide poor habitat. Tree cavity

roosters did not roost in 50-65 year old mixedwood stands and exhibited low activity in these areas relative to older stands (Crampton and Barclay 1998).

Physiological Constraints

Throughout the lab trials of arousing red bats with fire stimuli, the sound recording of fire only went to 20 KHz, whereas actual fires have sounds that range up to 60 KHz (Scesny 2006). Harrison (1965) showed that little brown bat hearing was affected by decreasing temperatures. Little brown bats could not hear below ambient temperatures of 12°C, and hearing below 20°C was much more depressed than at temperatures below 30°C (Harrison 1965). It is unknown how decreasing temperatures affect hearing or smell in red bats; however this may not be an important factor. Higher frequency sounds attenuate with distance and may not penetrate leaf litter barriers (Römer and Lewald 1992).

Although temperatures may be cold the night before a fire, if it is warm the day of the fire and there is a great amount of passive rewarming from the sun, it is probable that bats can respond quickly and arouse. In lab experiments on the effect of temperature change on torpid bats, temperature was continually increased from 10°C, with arousal induced in red bats at 20°C, whereas in other species subjected to the same treatment (*Myotis lucifugus, M. sodalis, Perimyotis subflavus, Eptesicus fuscus*) arousal began at 15°C (Davis and Reite 1967). At 5°C, red bats have lower heart rates than the other species in that study. Red bats metabolic rate rises at -5°C and remain elevated during torpor due to the potential lethal effects of freezing (Dunbar and Tomasi 2006). Arousal duration is longest at 5°C for it appears this temperature is the least costly while torpid; this conserved energy may allow bats to prolong arousals (Dunbar and Tomasi 2006). I do not know at what point during burn trials bats reached a homeothermic phase where

they were able to maintain an elevated body temperature and remain active for a variable period (Thomas et al. 1990). I categorized first response as the beginning of the warming phase, but made no further inferences because body temperatures were not recorded.

Conclusions

Hein et al. (2008) suggested that prescribed burns should not be conducted when temperatures the night before are $< 4^{o}C$. At these temperatures, Seminole bats would switch from roosting in trees to leaf roosts. However, in my study arousals occurred at 10, 11, and 18 min when the minimum temperature the night before was $0.8^{o}C$. Bats were not in normal roosting conditions at the burn lab, and fires were set relatively early, with a minimal amount of time to passively rewarm. I tested low temperature extremes at which these bats can arouse. Bats which have selected optimal roost sites will most likely react with a quicker escape response than observed in my study, especially if temperatures are above $10^{o}C$ at the onset of a fire. This arousal may also be enhanced by the increased CO levels present during actual fires. I recommend starting fires on north-facing slopes during minimal cloud cover and/or when temperatures $\geq 10^{o}C$ have occurred during the day. These conditions would be conducive to ground roosting bats on southern facing slopes that have had the opportunity to passively rewarm and become aware of approaching fire.

Although incidental impacts on other species in the forest habitat must also be considered when deciding whether to implement winter burning, I found that with increasing temperatures and the presence of wind, red bat reactions to incoming fires decreased in latency.

Forest management can have direct and indirect effects on bats, with indirect impacts having the greatest effect (Hayes and Loeb 2007), such as the formation of roost

trees and overstory tree mortality that produces gaps where foraging can occur (Carter et al. 2002). Monroe and Converse (2006) showed that instead of prescribed fire timing, yearly affects such as weather, predation, and competition have a greater impact on small mammal populations in a forest environment. This conclusion can be expanded to include bat species; the overall added benefits of sound management such as well-executed fire plans to a habitat are of greater importance than the short term detrimental effects of a fire.

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